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It has been proved that: (1) If (1.1) and (1.2) are differential equations which define the same system of paths then the functions $\Gamma^{i}_{\alpha\beta}$ and $\Lambda^{i}_{\alpha\beta}$ are related by the equations

$$\Gamma^{i}_{\alpha\beta} - \Lambda^{i}_{\alpha\beta} = \varphi^{i}_{\alpha\beta} = \delta^{i}_{\alpha}\varphi_{\beta} + \delta^{i}_{\beta}\varphi_{\alpha} \tag{4.3}$$

in which φ_{α} is a vector. (2) If (1.1) are the differential equations of a system of paths and φ_{α} is any covariant vector then there exists a second set of differential equations (1.2) for the same system of paths, the functions $\Lambda^{i}_{\alpha\beta}$ being defined by (4.3).

The formula (3.7) reduces to that obtained by Eisenhart on page 235 of this volume in the case when s is a function of t alone. This makes it evident that his work must be taken as referring to a geometry in which there is an element of distance ds defined by means of functions of position. In this sense his theorem on page 235 will be found not to be in contradiction with the theorem (2) above.

A DIRECT METHOD OF TESTING COLOR VISION IN LOWER ANIMALS

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1. When spectral lights of different wave-lengths are directed on the photoreceptors of lower organisms, their reactions show that one of the two lights is, physiologically, the more effective. Even when the unequal distribution of energy in the spectrum is equated for, there still remains a difference in the physiological effectiveness of the stimuli. (Laurens and Hooker.[1]) This difference must be dependent upon wave-length. But it is also evident to the color blind eye (Koenig[2]). We cannot therefore argue that the differential response on the part of the organism is proof of color division.

Researches which have approached the question of color vision in lower organisms by means of *conditioned behavior* have not been done with pure spectral lights. Even when pure spectral lights are used, the difference in brightness must be equalized, not, however, in accordance with the luminosity curve of the human eye, but with that of the organisms whose color vision is to be tested. Obviously it is difficult to obtain a luminosity curve free from extraneous factors from the reactions of organisms sufficiently complex and intelligent to exhibit conditioned behavior.

The method of conditioned behavior is not applicable to lower organisms and it meets with difficulties when applied to higher animals. Therefore, if we would study the evolution of reactions to color, we must cast about for another method.

Most theories of color vision postulate receptive systems maximally sensitive to certain wave-lengths which differ in some manner from those which are maximally sensitive to other wave-lengths. The difference, according to some theories, lies in the receptive substance of the eye (Young-Helmholtz, Hering); according to others, there are different "color perceiving" mechanisms in the brain which serve for perception of the different fundamental colors. (Edridge Green,[3] Houstoun,[4] and the various "Zone Theories.") Work on the human eye (Burch,[5] Abney,[6] Frank Allen[7] and others) shows that these receptive systems can be separately fatigued by strong monochromatic light.

If we can get evidence that the photo receptors of lower organisms can be differentially fatigued in a similar manner, it would indicate that the receptive system which is maximally sensitive to certain wave-lengths differs in some respect from the receptive system which is maximally sensitive to other wave-lengths, and this could be construed into something analogous to color vision. The following is a preliminary report of the results of experiments recently performed with this in view.

2. The animal decided upon was the fruit-fly, Drosophila. Specimens were kept in the dark over night and used in the dark adapted state. The apparatus consisted of two Hilger wave-length spectrometers** used as monochromatic illuminators and so set as to throw beams of light into opposite ends of a small horizontal tubular glass cell containing the flies. The sources of light were two 500-watt Mazda C stereoptican lamps.

The intensities of the light beams, differing as to wave-length were so regulated that the animals were not oriented in either direction. The lights were physiologically equal. As soon as this was accomplished one beam of light, called for convenience the "stimulating light," was intercepted by a screen and the animals subjected to the action of the other ("fatiguing") light. As soon as a marked decrease in the positive reaction of the flies to the "fatiguing" light was observed, the screen was removed and the animals subjected to the "stimulating" light again.

As soon as this was done, the animals usually oriented and crawled toward the "stimulating" light in spite of the continued action of the "fatiguing" light. The operation of the "fatiguing" light had thus upset the physiological balance between the two lights by fatiguing the apparatus maximally sensitive to this light, more than the apparatus maximally sensitive to the "stimulating" light. When such a test had been complete, it was repeated immediately, with the light that had been used as the "fatiguing" light arranged to "stimulate" and vice versa. In the second test, the animals were, of course, not dark adapted.

If, however, the two lights were of the same or nearly the same wave-lengths the results were quite different. The lights were balanced, the "stimulating" light intercepted, and the animals subjected to the "fatiguing" light. There was evidence of fatigue, but when the "stimulating" light was again allowed to fall on the flies, it was easily seen that the fatigue was not differential. The animals distributed themselves at random, between the two ends, just as they did when the lights were first balanced.

The spectrum was then scaled. The smallest difference in wave-length which showed conclusive evidence of differential fatigue was the unit used. Beginning at 385 $m\mu$, which is as low as the calibration of the instruments extend, the values were found as follows:

$$385\text{–}410,\ 410\text{–}430,\ 430\text{–}450,\ 450\text{–}500\ m\mu$$

The last determination was rather doubtful. At the intensity available the orienting effect of light above 500 $m\mu$ was insufficient to give conclusive evidence of differential fatigue. The distribution of these points and the fact that "hue perception" is at its maximum between 410 $m\mu$ and 450 $m\mu$ makes it appear that there may be two receptor systems, one for the blue-violet and one for the blue-green. Evidence for a third component seems to be lacking. According to Steindler[8] the hue perception curve of the normal human eye indicates the existence of three receptor systems.

3. It is planned to extend this work to other organisms and to work out the energy—time relationships of differential fatigue with different pairs of wave-lengths at different intensities.

The method should prove of value in analyzing the wave-length receptors of lower organisms, and its modifications and applications are numerous. It is applicable to the investigation of the pupil reactions, of the action current of the optic nerve and to similar problems. Perhaps one of its most interesting applications would be to ascertain the course of evolution of the color sense among lower organisms by means of photic orientation in crossed beams of light. The chief value of the method is its objectiveness.

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[2] Koenig, *Ges. Abhandlungen*, Berlin.

[3] Edrige Green, F. W., 1920, *The Physiology of Vision*. London.

[4] Houstoun, R. A., 1916, A theory of color vision. *Proc. Roy. Soc. London*, **A92**, 424–32.

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[6] Abney, Sir W. de W., 1913, *Researches in Color Vision*. London.

[7] Allen, Frank, 1920, Persistence of vision and the primary color sensations. *Amer. J. Physiol. Optics*, **1**, 94–134.

[8] Steindler, 1906, Der Farbenempfindlichkeit des normalen und farbenblinden Auges. *Sitz. Weiner Akad.*, **105**, 11a, 115–6.

** One of these instruments belongs to this Laboratory, while the other was loaned to us by the kindness of Professor G. H. Parker, Harvard University.

CHARACTERISTICS OF A SHORT WAVE OSCILLATOR AT VERY LOW PRESSURES

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Various investigators have experimented with three element vacuum tubes oscillating at a wave-length of the order of one meter. All of them have used commerical tubes, having a cylindrical arrangement of filament, grid, and plate.

Barkhausen and Kurz[1] discovered a type of oscillation which was apparently due to the motion of electrons in the tube itself, and was independent of the inductance and capacity of the external circuit. The computed time for an electron to travel across the tube, from filament to plate and back, under the potentials applied, agreed fairly well with the period of the waves as measured by means of Lecher wires coupled to the tube.

Whiddington[2] experimented with a similar type of oscillation, but he observed much lower frequencies and attributed the observed effects to the motion of ions instead of electrons. An explanation was given which involved a discontinuous emission from the filament.

Gill and Morrell[3] have experimented extensively with the Barkhausen type of oscillation, using commercial tubes made by the Marconi company, and have given an explanation of the effect which involves a natural mode of oscillation of the electrical system connected to the tube.

The work of Barkhausen and Kurz and that of Gill and Morrell was done with so-called "hard" tubes, which in the process of manufacture have been thoroughly heated to remove occluded gas and then sealed off from the vacuum pump. These men have assumed that they were dealing with a purely electronic phenomenon, and that no gaseous ionization was concerned.

The essential departure in the experimental arrangement in the present investigation was the use of a tube which was left permanently connected to the vacuum pumps, and was made with a ground joint to make the in-